Thermal Analysis of the Cold Neutron Moderator Cell in HANARO

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1. Introduction

The production of cold neutrons is one of the various research fields for the HANARO that is providing the source of neutrons. Cold neutrons are used extensively for studying the structure of condensed materials and fundamental neutron physics. The cold neutron source (CNS), installed in the vertical hole of the reflector tank at the HANARO, is the facility in which thermal neutrons pass through liquid hydrogen at approximately 20 K where they are moderated down to a cold neutron in a low energy range of 0.1 and 10meV. Cold neutrons are commonly defined as those having wavelengths longer than 4Å.

A 3-D thermal analysis model was developed to determine the temperature distribution in the cold neutron moderator cell by using the HEATING7.3 code [1], finite-difference heat conduction analysis code system. The temperature estimation for CNS is a very important factor to evaluate its thermal property and to perform a thermal stress analysis. The steady-state temperature calculations for the moderator cell are presented in this paper.

2. Methods

2.1 Configuration of the Cold Neutron Moderator Cell

The nuclear heat generated by neutrons and gamma rays in the liquid hydrogen and the moderator cell is removed by boiling liquid hydrogen. The hydrogen vapor generated in the moderator cell goes up to the heat exchanger through the transfer tube, where it is re-liquefied and returned finally to the moderator cell by gravity force, which is called a thermo-siphon loop [2].

The cylindrical moderator cell filled with the liquid hydrogen is manufactured by Al6061 and placed in the vacuum chamber that provides insulation for all the cryogenic components of the system. Its inner radius is 6.5 cm, while its outer radius is 6.6 cm and its height is 23.2 cm including the thickness of the Al6061. The shape of the moderator cell is a double cylinder with an open cavity type, which is good to make more cold neutrons and a lesser heat load. The inner cylinder has an open cavity towards the CN beam tube to remove the possibility of a cold neutron up-scattering and absorption. The center of the inner cylinder is shifted toward the CN beam tube by 0.5 cm for more brightness and the maximum radial thickness is 3 cm [3], as depicted in Fig. 1.

The liquid hydrogen serves both as a neutron moderator and a single-phase cryogenic coolant for the moderator cell. The liquid hydrogen flow rate is 2.5 g/s by a liquefaction. The hydrogen flow rate was chosen in order to produce a natural convection within the CNS that provides an adequate heat transfer of the hydrogen and the aluminum walls. Consistent control of the hydrogen velocity over the moderator cell and the heat exchanger is necessary because of the requirement to remove the nuclear heat from the moderator cell.

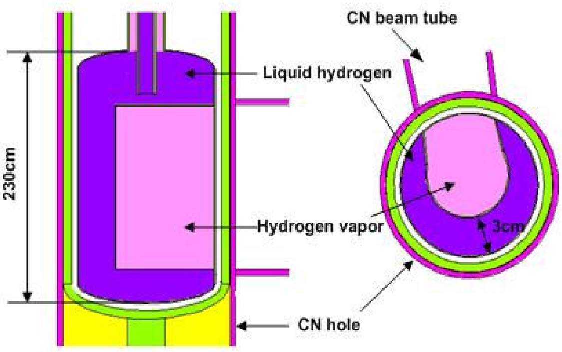

Figure 1. Double cylinder with an open cavity

2.2 Geometry Model

As the model complexity increases, 3-D effects, caused by non-uniform heating, and the presence of an inner cavity would have to be considered. A 3-D axisymmetric thermal analysis model for the half of the cold source cylinder near the reactor core was developed by using the HEATING7.3 code. With the origin of the cylindrical (r-θ-z) coordinate system [4] located at the center of the cylinder, the positive y-axis passes through the centerline of the CN hole. The calculation model uses 20,426 nodes to approximate the geometry of the complete cylindrical moderator cell.

2.3 Nuclear Heating

The total heat load is calculated to be less than 1 kW, of which about 0.456 kW represents the heat generated in the walls of the aluminum moderator cell, with a majority of the remaining heat load being generated in the hydrogen itself. With this distribution, the total nuclear heat load on the cold source moderator cell is 0.629 kW [5]. The total radiation heat load is expected to be about 3.0 W under the pressure of about 10^{-5} Torr.

2.4 Thermo-physical Properties

The material thermo-physical properties such as the density, the thermal conductivity and the specific heat, are essentially required for the calculation model as an input data. The data for the hydrogen and the Al6061-T6 properties at cryogenic temperature ranges are obtained from the literatures [6,7]. The temperature of the liquid hydrogen is 22 K at 1.5 atm.

3. Results

The results of the steady-state temperature calculations in the moderator cell are summarized in Table 1. The distribution of the temperature in the cold source moderator cell is approximated by a linear function of y, where the maximum temperature of 50.67 K occurred at the point on the inner cylinder closest to the reactor core. The minimum temperature of 21.75 K is located at the point on the outer shell farthest from the reactor core, that is, diametrically opposite to the location of the maximum temperature. The difference of the calculated temperature is slightly more than about 20 K between the maximum and average temperature in the moderator cell. The result could be an optimistic prediction for a thermal analysis in a moderator cell

Table 1. Temperature Distribution in Moderator Cell

Components	Nuclear Heating Rate		Maximum Temperature (K)
	(W/g)	(W)	
Outer Shell	0.58	208.2	50.67
Inner Cavity	0.72	91.7	21.82
Inner Tube	0.31	132.6	22.67
LH_2 in Outer Shell	1.93	168.9	21.75
GH_2 in Inner Cavity	1.64	4.0	21.82
LH_2 in Inner Tube	0.98	9.6	21.82
Others		13.9	
Total		629.0	

4. Conclusion

The 3-D heat conduction simulation of the moderator cell is performed to investigate the effects of temperature gradients within the moderator cell. Such a thermal analysis is useful for the safety analysis and operation strategies of a cylindrical moderator cell. Moreover, steady-state calculation results are planned for supporting the thermal stress analysis in a moderator cell.

Acknowledgements

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